to which we may again quote Whipple as follows (*1*): "There is no attempt to show that the results are not attributable to chance, and, indeed, the general run of the graphs is in accordance with the hypothesis that they are."

LITERATURE CITED

(1) WHIPPLE, F. J. W.
1925. DOES THE SOLAR HEAT STREAM VARY?
Nature (London), 116: 754–756.

(2) ABBOT, C. G.
1925. SOLAR VARIATION AND FORECASTING.
Smithsonian Miscellaneous Collections, 77: No. 5, p. 2.

(3) KIMBALL, H. H.
1925. SMITHSONIAN SOLAR-CONSTANT VALUES.
Mo. Wea. Rev., 53: 303–306.

(4) WHIPPLE, F. J. W.
1921. THE SIGNIFICANCE OF CORRELATION COEFFICIENTS.
Meteorological Magazine, 56: February, 20–21.

—*H. H. Kimball.*

In the investigation of any problem by the method of correlation, the real work does not begin until after the coefficient has been computed and its probable error determined. Even after everything possible has been done to insure against errors due to the nature of the data used, possible nonlinear regression, etc., there still remain numerous considerations which must be taken into account in addition to the mere face value of the coefficient; the difficulties in the way of arriving at conclusions which can be trusted, and the pitfalls awaiting, are numerous.

The problem quoted by Clayton on page 524, e. g., illustrates the following particular points: The correlation coefficient by itself is not an index to physical cause and effect, but merely an index of concomitant variations, however these may be brought about (the true measure of the degree of this relationship is the *square* of the coefficient). Where we know a relationship must exist, the computation of the coefficient and the derivation of the regression "equation" serve the purpose of providing a quantitative expression of the relation, from which more or less useful predictions may be made; but in any case, while revealing to what extent fluctuations in one quantity are accompanied by proportionate fluctuations in another, the coefficient throws no light on the causal mechanism connecting the two.

The gross coefficient may result from the action of a third influence affecting each of the two variables correlated; or the mechanism may be of a much more complicated character. In Clayton's example, fluctuations of run-off did not accompany fluctuations in rainfall over the watershed, and the zero correlation reflected this fact; and as long as knowledge was confined to these two things, rainfall could not be used to predict run-off—these two variables are mathematically independent. So, if a large coefficient had been found, it would not have proved rainfall and run-off to be causally connected (though, in this case, considerations external to statistics would have suggested this as the common sense interpretation); but nevertheless, a knowledge of one would have enabled calculations of the other to be made, since they would vary together, for some reason or other. The tracing of relations of cause and effect, and the interpretation of gross coefficients, as well as the improvement of the regression equations, involves the computation in many cases, of net (partial) and total coefficients also.

Caution must always be exercised in applying the customary formulas and criteria to small samples, for they do not then always hold. Attention should also be invited to Walker's discussion of the criteria for the reality of correlation coefficients, Mem. Ind. Met'l Dept., vol. 21, pt. ix, pp. 13-15, 1914.—*Edgar W. Woolard.*

MONTHLY PRESSURE VARIATIONS IN THE NORTHERN HEMISPHERE AND SEASONAL WEATHER FORECASTING

By ALFRED J. HENRY

SYNOPSIS

The variations of monthly mean pressure for stations in the Northern Hemisphere, as published in Reseau Mondial for the eight years 1910–1917 were studied with a view of determining the frequency, geographic extent, and distribution in latitude and longitude of the pressure anomalies in the Northern Hemisphere for that period. The isanomalies for 67 months out of the 96 that were available were charted and studied. Many of these were featureless in the sense that the amplitude of the anomaly was small and frequently in an opposite sense in closely adjacent regions. In about 10 per cent of the cases considered the anomalies were pronounced both as to amplitude and extent of area involved These are described in some detail, and the relation of the anomalies to current and subsequent weather in contiguous areas is discussed.

The paper closes with a brief review of the method of seasonal forecasting now practiced in India and tentative suggestions are given looking to the development of a method of seasonal forecasting for the United States.

Variations from normal pressure.—The air pressure at any given place is conditioned by several separate and distinct causes, viz (*a*) the intensity of incoming and outgoing radiation of which the incoming solar radiation is by far the most important; strong outward radiation from the atmosphere and the earth causes the air temperature to fall, the air mass to contract, sink, and thus the opportunity for the inflow of fresh accretions of air aloft and a raise in pressure is brought about; (*b*) the rotation of the earth on its axis modifies the speed and direction of air motion, causes it to be heaped up in places and set in swift motion at others whereby the pressure is elevated at the one and lowered at the other. The third or (*c*) class of pressure variations which form the subject of this paper are due to a combination of the two causes above enumerated, in combination with those associated with the origin and movement of cyclones and anticyclones.

In general, monthly mean pressure for any given place will depart, more or less, from the normal in proportion to the frequency of cyclonic and anticyclonic systems experienced at the given place.

Class (c) variations.—In their simplest form these variations are experienced in the paths of areas of low pressure (cyclonic systems), the amplitude being greatest at and near the center and diminishing thence in all directions. It is perhaps needless to say that pressure falls with the approach of a cyclone and rises approximately as the center of the disturbance crosses the meridian of the observing station. If then more than the normal number of cyclones for the season pass over or near to the station the monthly mean pressure will, as a rule, be less than normal and the magnitude of the departure will be an index of the frequency of cyclonic systems passing over or near the station. Likewise a large number of anticyclonic systems passing over a station or lingering over it an unusually long time will result in a positive departure from the normal. Small departures either above or below normal are, as a rule of little significance.

Amplitude of the variations.—It is a matter of common knowledge that the amplitude of the variations under discussion increases with the latitude and reach a maximum in the cold months. I have however, computed the eight-year average for eight stations in the tropics, and find that the average variation, regardless of sign is 1.0 mb. for December, January, and February, diminishing to a minimum of 0.7 mb. In April, September, and October. The mean variation in winter, in high latitudes, apparently may be as much as plus or minus 6 to 8 mb. and a single monthly variation of plus 34.1 mb. was registered at Dawson, Yukon T. in December, 1917.

As Hann pointed out some years ago the maximum day-to-day pressure variations occur over the oceans and the minimum over the land.

Frequency of variations of ±5 mb.—The maximum frequency of variations of the magnitude of ±5 mb. or greater, is in the zone of 60° to 70° in the Northern Hemisphere and quite probably the same holds true for the Southern Hemisphere. Positive and negative anomalies occur about equally on the average of the year, but some years are much richer than others in the number of positive or negative anomalies, thus 1912, 1915, and 1917 were unusually rich in positive anomalies, while 1913 and 1914 were fruitful in negative anomalies.

In all 67 charts have been made from the published data of the Reseau Mondial; many of them are featureless in the sense that the amplitude of the anomalies is small and irregularly distributed.

The following comments of a general nature are suggested by a study of the charts. Variations of large amplitude and wide extent seem to build up gradually to a maximum and then sometimes slowly, sometimes quickly disappear. Positive anomalies disappear much more quickly than negative. This may be ascribed to the fact that a positive anomaly may be thought of as a heaping up of cold dense air which naturally gravitates equatorward and therefore is constantly being deprived of its original frigidity. It contains within itself the seeds of destruction. On the other hand the large and enduring negative anomalies arise in or close to the great circumpolar whirl in certain parts of which surface conditions of temperature and moisture prevail greatly in excess of those due to the latitude; the low pressure thus originating is maintained in part by the absorption of fresh cyclonic systems which are often fed into the original low pressure system for weeks at a time, and in part by the centrifugal force of the general circulation in the polar region.

These great pressure anomalies do not seem to have the attributes of a separate and distinct entity but are similar to statistical [1] cyclones and anticyclones. That they have an apparent movement from place to place is obvious; that movement however, is apparent rather than real, in many cases the apparent shifting of the geographic position of the center of the anomaly—the region of greatest departure—can be explained by the fact that a relatively larger rise in pressure has taken place in one part of the original anomaly than in other parts, thus the center of the anomaly is automatically displaced in one direction or another.

The great negative anomalies apparently arise more readily over the sea than the land. The Mediterranean and the seas to the eastward may be the contributing influence that produces large negative anomalies in that part of Europe when such is not the case for the corresponding latitudes in North America.

[1] The word statistical is used in the sense adopted by English meteorologists in recent publications in referring to the Iceland "cyclone" and others of the same nature. The present writer would go farther and use the word to connote those semipermanent anticyclones that have hitherto masqueraded under the highly respectable, though inappropriate term "action centers."

Discussion of individual months.—Only about 10 per cent of the charts made show pronounced anomalies; these will be discussed on the pages following:

November, 1910.—This month was characterized by high pressure in the Arctic Basin and adjacent parts of America and Eurasia, also over parts of the Pacific; the greatest excess was experienced over the west Greenland coast (20 mb.) The high pressure extended from the Labrador coast in a direction a little north of east by way of Greenland, Iceland and Russia to western Siberia or about half way around the globe. Paralleling the southern margin of the region of high pressure and in a zone about equal in length pressure was below normal by as much as 9 to 12 mb. in northwestern Europe and in the vicinity of St. Johns, Newfoundland.

In the following month this great excess of pressure in the polar basin had practically disappeared, although remnants of the midlatitude deficit remained.

In the United States the month was one of deficient precipitation with temperature below normal east of the Rockies and above normal west thereof. The low temperature in eastern districts as also the dry weather may be attributed in part at least to the great depression of the barometer in the North Atlantic in the vicinity of the Canadian Maritime Provinces.

January, 1914.—In this month pressure was below normal over the greater portion, if not the whole, of the polar basin and, indeed, over large parts of the continental areas adjacent thereto. In North America there were two centers of maximum depression, the eastern one in the vicinity of St. Johns, Newfoundland, and the western one at Prince Rupert on the British Columbia coast; in intermediate regions, particularly along the 50th parallel of north latitude, pressure was also much below normal. In the Eurasian continent the principal depression amounted to close to 20 mb. in northern Russia, decreasing thence to 10 mb. in central and northeastern Siberia.

The beginnings of this great depression may be traced back to October, 1913. In that month a very considerable depression of the barometer appeared in southern Russia and a lesser one over the eastern Atlantic at the Azores. In November, 1913, two centers of depression appeared almost on opposite sides of the globe, the first and greatest in geographic extent being centered over Iceland and the second over Alaska; smaller depressions appeared over Asia, thus indicating a general weakening of the circulation over that continent. December, 1913, was characterized by a single very large area of diminished pressure that stretched from Spitzbergen to the Caspian Sea and beyond, and two areas on the North American continent, which in the light of more complete observations may have been but a single area that extended from Greenland across British North America to Alaska. Hence it is clear that the January, 1914, depression did not come into being suddenly but was a gradual development beginning three months earlier.

Having reached its maximum in January its subsequent history is one of gradual degradation both in the amplitude of the variations and in the extent of territory affected. Two months later, in March, 1914, high pressure had overspread the North American continent, including the Aleutians and most likely a portion of the North Pacific; pressure remained low, however, over the greater part of the Eurasian continent in March. In the following month high pressure from the Atlantic spread eastward over middle Europe.

The geographic center of diminished pressure, by which is meant the region over which the greatest fall occurred, did not have any progressive movement.

The depression of the barometer in January, 1914, above described, was due to the passage of a chain of cyclonic systems of Pacific origin across North America in about 50° north latitude, as is clearly shown by the weather charts for the Northern Hemisphere published in 1914 by the United States Weather Bureau. These maps show also that cyclones of Gulf of Mexico origin moved to the northeast over eastern United States and thus augmented the flow of cyclonic storms from the Pacific; these storms continued across the Atlantic and over a large part of the Eurasian continent. A positive anomaly of considerable magnitude overspread the British Isles, and thus the cyclonic storms were shunted farther toward the Arctic regions than is usual. While the flow of cyclones around the pole during this month was occasionally interrupted by the intrusion of an anticyclone, such interruptions were few.

Weather in United States.—Temperature in the United States and Canada was exceptionally high for a winter month; precipitation was deficient in the Gulf States and in excess on the Pacific coast and snowfall was generally light.

December, 1915.—In this month a large belt or zone of low pressure in latitudes 35° to 50° north almost encircled the globe. Pressure was lowest over the North Atlantic from the Canadian

Maritime Provinces to the British Isles, thence along the 50th parallel to the Kamchatkan Peninsula and probably to the Alaskan coast; pressure was also low over the North American continent. On the polar side of this great depression there was a single rather restricted region of positive pressure departures centered between Iceland and the east Greenland coast (12.9 mb.).

Weather in United States.—The month was characterized by a movement of anticyclones from the Pacific rather than from Canada, consequently temperature was mostly above the average and precipitation was also greater than normal. In eastern sections temperature was below normal, due doubtless to the area of negative pressure anomaly over the Atlantic. The immediate sequence in pressure distribution is described in the next following paragraph. Instead of a single region of strong positive anomaly as in December, 1915, there were at least two; the first occupied the North Atlantic, northern Africa, and the western Mediterranean the second occupied Alaska, extending thence southeastward to the United States and thence to the North Atlantic.

January, 1916.—This month was characterized in the United States by a large number of cyclonic storms, many of which entered the continent below the mouth of the Columbia River. Heavy rains fell in California and elsewhere to the eastward, resulting in places in destructive floods. The world pressure distribution therefore is of especial interest. The pressure distribution of the immediately preceding month is described in the preceding paragraphs; the fact that anticyclones moved into the United States from the Pacific leads to the inference that high pressure prevailed over that ocean in December, 1915.

The outstanding feature of the departure chart for January, 1916, is an area of positive abnormality centered over Bering Sea and Alaska (17.3 mb. at Kodiak Island). Directly south of this area a tongue-shaped area of negative pressure departure with its maximum on the Oregon coast penetrates the Great Basin region; pressure was high over the Atlantic and the western Mediterranean, a reversal from the conditions of the previous month.

It seems reasonable to ascribe the movement of cyclones in low latitudes in the United States to the prevalence of high pressure in Alaska and the Northeast Pacific, and to the presence of low pressure areas over the Pacific in immediate contact with the high pressure in interior Alaska.

December, 1916 and 1917, respectively.—These two months are considered together because both were of the type showing exceptionally large positive departures in the polar basin and contiguous territory. In both months there was a center of great positive departure in Greenland and on the opposite side of the globe in northeastern Siberia with overflows to Labrador in both months, but in 1917 only to Alaska where a positive anomaly of 34.1 mb. (1 inch) was recorded. This month was preeminently the month of maximum positive pressure departure in the polar basin during the 8 years of record; it was also the fore-runner of the cold winter of 1917–18 in the United States.

Annual variations.—During the eight years there were two periods of rather widespread and intense negative and two of positive variations, respectively. The first negative variation began in the European Polar Basin and ended there. It endured from December, 1912, to April, 1913; the center varied in its position from month to month. The second great anomaly was that of October, 1913, to April, 1914, already described. The first extensive positive anomaly was that of December, 1916, and it was localized in the Polar Basin and adjacent areas of both continents; the second great positive anomaly occurred just 12 months later, viz, in December, 1917. Both were effective in producing cold weather in the United States, and the first-named was apparently the cause of a cold spring in 1917 west of the Rockies. The December, 1916, anomaly was associated with a very extensive negative anomaly that spread from the Canadian Maritime Provinces to the central Mediterranean. This fact doubtless made the spread of cold weather equatorward more easily accomplished than would otherwise have been the case. In the December, 1917, positive anomaly, the cold weather came to an end, in the United States at least, in February, 1918. The records for 1918 for places outside of North America are not yet available.

It is obvious that one of the first steps toward predicting an event is to discover when, where, and how the event occurs. I therefore now pass to a consideration of the influence exerted by the pressure abnormalities hereinbefore described and others not mentioned upon current weather in the United States.

EFFECT OF PRESSURE VARIATIONS ON TEMPERATURE

It rarely happens that monthly mean temperature in the United States for a period as long as a month is uniformly above or below normal in all parts of the area. If when it is everywhere above the normal we call the month 100 per cent warm and in like manner every month that is everywhere cold a month 100 per cent cold, and if we take into account only the eight years under consideration it is found that out of the 96 months only 8 of them could be considered as 100 per cent warm or cold. The warm months were March, 1910, November, 1913, January and October, 1914; the cold months were February, 1910, November, 1911, and December, 1917.

Examining the pressure departure charts for these and other months it is readily seen that the single dominating feature, in the case of warm months in the United States and Canada, is a rather pronounced depression of the barometer over northwestern Canada, interior Alaska, and by inference over the northeastern Pacific. A contributing cause in winter is a positive abnormality over the western Atlantic about north latitude 30° to 40°.

If warm weather is to be forecast for the United States and Canada we should be able to foresee that the path of cyclonic systems across the continent would be essentially along the 50th parallel of north latitude and that anticyclones for the most part would enter the continent from the Pacific rather than descend from the high latitudes of the interior of the continent. The two conditions just named are supplementary the one to the other. Low pressure over Alaska and the Canadian northwest is inimical to the development and maintenance of anticyclones, and experience shows that in those conditions anticyclones are given off from the North Pacific HIGH and therefore are not attended by severe cold.

The conditions for 100 per cent cold weather control are almost the exact reverse of those just described, viz, high pressure in Alaska and the Canadian northwest that extends southeastward to the eastern slope of the Rocky Mountains in Montana and Wyoming. In such a pressure distribution anticyclones advance in a southeastward path by way of the Missouri Valley to the neighborhood of Iowa, where they spread somewhat and move more in a true east direction. A contributing cause of low temperature in eastern sections of the United States is a pronounced depression of the barometer over the North Atlantic in the neighborhood of the Grand Banks. So much for the broader features of temperature and pressure relations.

A temperature distribution in the United States that frequently occurs is that best characterized by the expression "warm east, cold west of the Rockies." The mountains in these cases serve as a climatic divide between the above-normal temperature on one side and below normal on the other. Although the statistics are not at hand, I am of opinion that many of the anticyclones that move southeastward from Canada by way of the Missouri River Valley are shallow—that is, the extreme cold is confined to surface layers and there is not, therefore, an overflow of cold air toward the Pacific slope. Such overflow even in the absence of a mountain barrier would be greatly hindered by the prevailing eastward drift of the currents up to the cirrus level.

Cold weather in the Plateau and Great Basin [2] region seems to be due to the fact that in some seasons offshoots from the North Pacific HIGH impinge upon the California coast, drift north-northeast, and recurve to the southeast over the Great Basin region, where, due to the peculiar topography of that region and perhaps to a surface cover of snow they frequently lodge for days at a time. A snow cover and the intense outward radiation of that dry region must aid materially in prolonging the existence of anticyclones which come within its borders. These Great Basin anticyclones serve also to prevent cyclones from entering the continent over Oregon, northern California, and Washington, and thus their presence is inimical to rainfall in those States.

Another control of the temperature west of the Rockies is that exercised by high pressure over western Canada that apparently merges with the North Pacific High and forms a barrier over which offshoots from oceanic cyclones can not pass. (See Chart III, Tracks of Low Areas, April, 1917, MONTHLY WEATHER REVIEW.) When this happens many secondary cyclones develop over the southern Plateau and Rocky Mountain region and thus facilitate the indraught of cold northerly winds in their rear.

SEASONAL FORECASTING

The problem.—GIVEN, an atmosphere such as possessed by the earth which by reason of its movement through countless years has reached something akin to equilibrium in its moving parts, but which, however, is being constantly disturbed by both the local and the general circulations due to contrasts in temperature arising from greatly diversified cloudiness, the unequal heating of land and water surfaces, the change of seasons, and other causes:

REQUIRED.—To distinguish when and where the local and the general circulations will be most disturbed, the character of the disturbance, and finally, the effect of such disturbance on the weather a month or a season, hence.

The methods of the day-to-day forecaster who bases his predictions upon the predetermined geographic position of the significant barometric formations already in existence must be discarded as hopelessly impossible when an attempt is made to determine in advance the changes in geographic position, the growth and decay of cyclones and anticyclones already in existence, and the time and place of origin of new ones.

The seasonal forecaster must adapt himself to the formulation of a broadly generalized forecast, qualitative rather than quantitative. Is such a forecast for the changeable weather of temperate latitudes possible under present conditions? By present conditions I am referring to the lack of precise information as to current weather over large parts of the land areas and over practically all of the water surface of the globe.

The available printed meteorological records assembled for the globe as a whole cover but eight years, and for parts of Asia and Europe the continuity of the observations was broken by the World War. It is a question, moreover, whether the usual meteorological observations of pressure, temperature, moisture, wind direction, and speed and the face of the sky furnish in themselves sufficient data for the making of seasonal forecasts. Properly to answer this question would involve the critical examination of existing meteorological records of all time in a search for correlations between the weather in various parts of the globe. Sir Gilbert T. Walker, Director of the Meteorological Service of India, 1904–1924, has organized and prosecuted such a study and has given the results in a series of papers (*1*).

It is of particular significance in this connection that the only outstanding example of seasonal *weather* forecasting, or more specifically of seasonal *rain* forecasting, by an organized weather service is that of India. This service has regularly made since 1908 a forecast of the probable intensity of the monsoon rains of India several months in advance of the breaking of the monsoon.

Without detracting in the least from the efforts of Indian meteorologists to develop seasonal forecasts of rainfall on a scientific basis it should be remembered that there are several important factors in determining the rainfall of India that do not obtain elsewhere on the globe. Among these may be mentioned the following: (*a*) India is the only considerable land mass of the Northern Hemisphere that extends well into the Tropics, giving it therefore more stable weather conditions than prevail in the Temperate Zones; (*b*) the prevailing winds of the rainy season of India before passing over the land have traversed 4,000 miles of equatorial water, thereby absorbing both heat and moisture before impinging upon the land; and (*c*) the mountain systems of India are favorably disposed for augmenting the natural rainfall.

The four variables which enter into the formula used in forecasting the intensity of the monsoon rains of India are as follows: (*a*) Accumulation of snow in the Himalayas in May; (*b*) the current pressure at Mauritius; (*c*) South American pressure, March, April, and May; (*d*) the current rainfall in Zanzibar.

The monsoon breaks in June.—The data necessary to complete the formula become available late in May, so that the interval between the issue of the forecast about the first week in June and the coming of the rains is not a long one.

What most interests us in the formula above mentioned is the fact that pressure in far-off Argentina and Chile in March, April, and May varies in an opposite sense to that of India in June and July. The story of the discovery of this barometric seesaw, independently by the Lockyers and Bigelow in 1902, is an interesting one. Suffice it to say here that the English scientists endeavored to associate terrestrial pressure changes with the outbreak of solar prominences. In the course of the investigation it was shown that there were two great types of barometric variations, one varying directly with the prominences, the other inversely. Out of this study, which was not organized with reference to the problem of seasonal forecasting, came the important fact that pressure in South America in April and May varied inversely as that of India *two months later*, a discovery of much importance to Indian meteorologists.

Unfortunately a relations such as subsists between South American and Indian pressures is not known to exist between any other two regions, one of which must be in North America, in order to use pressure relations as a basis for seasonal forecasting for the United States.

Another case of barometric seesaw which might be of value in long-range forecasts, were it possible to predict the future pressure at one or the other of the two regions, is the relation which exists betweeen the pressure of two of the so-called "action centers."

Several European meteorologists, especially Meinardus (*2*) have shown the practical application of this relation to long-range forecasting.

[2] The term "Great Basin" as used in this paper refers to that portion of the western Cordilleran region which is characterized by wholly interior drainage, more especially the northern portion, or, roughly speaking, southeastern Oregon, southern Idaho, southwestern Wyoming, northern Utah, and northern Nevada. Representative Weather Bureau stations within this area are: Salt Lake City, Utah, Winnemucca, Nev., and Boise, Idaho.

In 1904 Hann pointed out that 80 per cent of the cases of great positive pressure anomalies at the Azores corresponded to negative anomalies at Iceland. I have examined the record of the pressure anomalies at the two places above mentioned for the years 1910–1917 and find that when only the anomalies of ±5mb. or greater are considered the statement by Hann is justified. Considering the months when the anomaly was ±3mb. or less it turns out that in 48 months of the 96 the variation was in the same sense in 20 cases and in an opposite sense in 28 cases. It was noticed, however, that at times of widespread variations from the normal, as in February, 1912, December, 1917, and other months, the variations were in the same sense rather than in an opposite sense. This would seem to indicate that both places respond in the same sense to great changes in the general circulation, excepting only that the magnitude of the response is conditioned by the latitude of the respective regions.

Hitherto in this discussion only contemporary pressure relations have been considered. If now we wish to learn whether a relation exists between the current pressure in one part of the globe and the pressure one, two, or three months later in some other part of the globe, recourse must be had to the statistical methods so ably practiced by Walker.

The correlation coefficient between Azores pressure, June to August, inclusive, with Iceland pressure for the same months, as computed by Walker, is −0.48, and the sign being minus indicates a reverse rather than a direct relation—that is to say, pressure at Iceland is low when it is high at Azores, and vice versa. The coefficient Azores pressure with that of Iceland one-quarter previous is, however, −0.06, an amount so small as to be without significance.

If we take Bermuda and St. Johns, a pair of meteorological stations on the western side of the north Atlantic, situated in some respects like the Azores and Iceland on the eastern side, and disregarding the magnitude of the variations, it is found that for the same eight-year period the variations were in an opposite sense in 54 per cent of the months and in the same sense in 46 per cent. Considering in the same manner the variations between Bermuda and the Azores, a variation in the same sense was found in 70 per cent and in the opposite sense in 30 per cent of the months, thus confirming the belief that pressure of the north Atlantic over the same general latitudes varies as a rule, as a single geographic unit.

The late Professor Garriott in 1908 announced (*3*) that—

> The character of the barometric distribution over the Pacific Ocean and the continent of Asia indicates the development or approach of storms and high pressure areas that will appear on the west coast of the [North] American Continent; and barometric conditions over the [North] Atlantic Ocean and Europe indicate the direction and speed of the movements over the North American Continent.
>
> Marked departures in the Asiatic area indicate the general character of the weather of the United States for a period of about two weeks in advance; and Pacific pressure conditions and changes furnish a key to weather changes that will occur on the Pacific coast of the United States 3 or 4 days in advance and indicate the character of those that will occur over the eastern portion of the United States 6 to 7 days in advance. * * *

At the time the above was written Garriott was making weekly forecasts for the United States and he continued to do so until his death in 1910. The revival of the weekly program by his successor on the Weather Bureau forecast staff Mr. E. H. Bowie in December 1913 is too recent to need discussion.

I have been interested, however, in a comparison between the pressure abnormalities of central Siberia and those of Alaska suggested by Garriott's studies. Using the 91 months for which the data appear in Reseau Mondial it was found that for contemporary pressures that Siberia varied in the same sense as Alaska in 45 months and in the opposite sense in 44 months, the variations in 2 months being indefinite; if, however, account is taken of only those variations that amounted to as much as ±3mb. in one or both regions the result is different, for example, variations of that amount occurred in 69 months or 76 per cent of the time. These variations were in the same sense in 49 per cent of the months and in an opposite sense in 28 per cent; they were indefinite in the remaining 23 per cent. Comparison was also made between central Siberian pressures and those of Alaska one month later, variations of ±3mb. only being considered. The result is given below:

Variations in the same sense	24 cases,	41 per cent
Variations in opposite sense	21 "	36 "
Variations indefinite	13 "	22 "

In the comparison it was noted, however, that at times the variations would be in an opposite sense for several months at a time and then the opposition would break down, so it is quite probable that forecasts based on an expected change in the pressure distribution in Alaska would be successful in a small per cent of cases. In the long run however there seems no ground for the belief that changes in pressure distribution in Siberia afford sufficient ground for forecasts for the United States, 10 days to 2 weeks in advance.

Walker (*4*) in discussing the correlation coefficients of central Siberian pressure with those of Alaskan and North Pacific pressure, says:

> In the winter table it is mainly with two quarters later that significant figures occur. High pressure in Central Siberia in winter is then followed by low pressure in San Francisco and high pressure in Alaska—i. e. by decreased oscillation in the North Pacific. * * *
>
> In summer central Siberia is fairly typical of the second group of the previous paper; i. e., low pressure there is associated with low pressure in Iceland, Alaska, and Northwestern India. * * * None of the coefficients individually is big enough to demonstrate reality, but the group of consistent relationships is too marked to be produced by accident.

Okada has worked out the relationships between pressure and temperature at Zikawei, a station on the Chinese coast at Shanghai, which he considers as representative of the Siberian HIGH. He finds that a rise in pressure is associated with a fall in temperature, the physical explanation being that a variation in the intensity of the Siberian HIGH during the winter causes corresponding variations in pressure at Zikawei and these bring cold northwesterly winds to that station. This relationship is of course one of contemporary conditions. Assuming that there is a lag between pressure variations in Siberia and weather in Japan some months later, Okada investigated the feasibility of forecasting temperature in Japan from Siberian pressure several months previous. He has published four notes on the results of this investigation (*5*).

The same author has since published two other papers "On the possibility of forecasting the summer temperature and the approximate yield of rice crop for northern Japan." (*6*).

The first paper deals with the facts established empirically that the August temperature in northern Japan, varies in harmony with that of the March pressure difference, Zikawei-Miyazaki and that of the South American pressure for March to May. In regard to these variations Doctor Okada remarks:

But, as in all efforts at the solution of seasonal forecasting there are some tantalizing exceptions in this harmony of the pressure and temperature variation. Hence we can not hope to establish a definite law of prediction or to calculate the approximate August temperature many months in advance. But the method described in this paper, though professedly imperfect will serve to show at least the sense of variation of the air temperature of the coming August and yield of rice crop in northern Japan at the beginning of June, when we have the telegraphic reports of the pressure data from Miyazaki in southern Japan, Zikawei in China, Santiago, and Buenos Ayres in South America.

In the second paper Doctor Okada first correlates mean temperature in winter at Nemuro, in northern Japan, with yield of rice crop in Hokkaido. He then correlates mean winter temperature at Dutch Harbor in the Aleutians with yield of rice in Hokkaido and deduces a coefficient of -0.631 (± 0.078) and from this he concludes

(1) Lower the mean temperature for January to March at Nemuro, in the previous year, lesser the yield of rice crop in Hokkaido than in previous year.

(2) Higher the mean temperature for January to March at Dutch Harbor than in previous year, lesser the yield of rice crop in Hokkaido than in previous year. Lower the winter temperature at Dutch Harbor greater the yield of rice crop in Hokkaido.

Mossman (*7*) also has made valuable contributions to the literature on seasonal weather correlations, his work being mostly confined to regions of the Southern Hemisphere.

It is due to Mossman that we have an account of a pronounced case of correlation that subsisted for a period of 17 years and then disappeared. The correlation was that between the rainfall of Trinidad (lat. 10° 40′ N.; long 61° 31′ W.) and of Azo, Argentina, (lat. 36° 31′ S.; long. 56° 46′ W.) and the period of years was 1878–1894. For these years a correlation coefficient of 0.79 (± 0.06) was found between the rainfall of Trinidad and Azo six months later, but when the entire record of 50-odd years is used the large correlation coefficient vanishes. Azo is in the south temperate zone and 2,850 geographical miles distant from Trinidad and Mossman naturally inquires whether the pronounced correlation as above was purely fortuitous or subject to cyclical repetition. Since weather changes in temperate latitudes drift from west to east we should expect to find more or less correlation between points along an east/west line. Such a correlation has been found between the temperatures at San Diego, Calif., and Jacksonville, Fla. (*8*).

Mr. Charles D. Reed in charge of the Des Moines, Iowa, U. S. Weather Bureau station has shown (*9*) that the mean June temperature of the State of Iowa is related in a definite way to the immediately following mean temperatures of July. August, and September, the correlation coefficient being $0.559 \pm .078$. The relation applies, however, only to a group of surrounding States and becomes less and less with distance from Iowa. A physical reason for the relation is not at once apparent; it does however, emphasize the importance of studying monthly sequences of the weather.

Seasonal forecasting from ocean temperatures.—The influence of the temperature of oceanic waters on the climate of adjacent land areas has long been known. With this knowledge as a starting point a number of investigators have endeavored to relate the temperature of the surface water in one or more of the best-defined currents of the North Atlantic, the Gulf stream and the Labrador current, for example, with the weather of northwestern Europe after an interval of several months. Pettersson, Meinardus, Hildebrandsson, and others have sought to find in the strength of the pressure gradient between the Azores and Iceland the key to the wind circulation of the intervening oceanic waters and have pointed out the probable results of increased wind circulation upon the distribution of ice in polar waters; since the increased flow of ice-bearing waters into the Gulf Stream might be expected to lower the temperature of that stream and this in turn would tend toward increased pressure in the neighborhood of Iceland. it is easily seen that the end result might have an important bearing upon the weather of northwestern Europe.

Exner (1913) made a systematic investigation by the method of correlation coefficients of the relations between the monthly deviations from normal of pressure and temperature for a number of stations in the Northern Hemisphere for the winter months, December–February.

The correlation coefficients between polar pressures and pressures in lower latitudes when plotted on a map show a region of high positive correlation around the pole, based mainly on high latitude stations of Europe and Asia, and a region of negative correlation over the Mediterranean, thus indicating a "see-saw" in the pressure relations of high and low latitudes, respectively. This result, however, refers to contemporaneous pressures and therefore has no special significance. The meteorological conditions in the north portion of the North Atlantic have been investigated to a greater extent, perhaps, than those of any other of the great oceans.

With respect to using the data of ocean temperatures in seasonal forecasting, Commander Hepworth, marine superintendent of the British Meteorological Office, sums up the situation in the following excerpt (*10*):

If, in connection with long-period forecasts of weather in these islands, sea surface temperature data be utilized at any future time, it will be necessary that a larger number of recent reliable observations be available weekly for all parts of the North Atlantic, than are available at present.

Without such a complete and continuous record it is impossible to interpret with accuracy the changes in the intricate distribution of sea surface temperature or to follow the movements of the respective water layers of Equatorial and Arctic origin * * *

Every one interested in the meteorology of the sea must know that the principal hydrographic services of the world do not publish or circulate current data of ocean surface temperatures and that to compile from their archives the current data of water temperatures for any one of the great oceans for a single month is a task totally beyond the ability of a single investigator. Hence we should take with a certain mental reservation the statements that occasionally appear in the public prints to the effect that ocean temperatures indicate thus and so for the coming years.

THE OUTLOOK FOR SEASONAL FORECASTING IN U. S.

As previously stated, the only seasonal weather forecasts now being made by an organized weather service are those of the Indian Meteorological Department. I have taken considerable pains to indicate the reasons why the method developed by that service is not of general application.

In the latest paper on the subject (*11*) there is a note of encouragement which I quote. After discussing the meteorological controls of the Pacific, Sir Gilbert remarks:

There are, however, grounds for satisfaction in the consistency of the relationships ascertained. Turning to the table in parargaph 57 above, if we examine the 150 significant coefficients between the 11 representative centers there enumerated, we shall find that the classification just given directly explains the sign of 149 of them. The solitary exception is the negative effect of Java rain (October to February) upon peninsula rain of the succeeding monsoon.

This consistency is very remarkable and supports the view that seasonal forecasting is capable of wider application than at present.

As hereinbefore indicated the pressure distribution that is associated with warm months and cold months in the United States and Canada is known, but as yet no promise is held out of our ability to forecast the pressure distribution of the North Pacific for a season in advance; moreover, the great accumulation of cold air in the polar basin of December, 1916, and December, 1917, appears to have been unattended by any thus far recognizable preliminaries, although in both cases exceptionally high pressure prevailed in various parts of the Northern Hemisphere, which apparently were consolidated in the polar basin in the months named. This is, however, merely an assumption that will have to be confirmed by many more years of observation.

The most important single variable involved is without question the variations in North Pacific pressures one quarter in advance and the influence of such variations upon the weather of North American Continent. A study of this variable would naturally require several collateral studies, for example, as to whether or not variations in the intensity of the Siberian HIGH of the cold season have a pronounced influence upon Pacific pressures to the east of Japan, and, if so, how far can they be traced? Another study might be concerned with the possible influence of early or late snowfall in the northern Canadian Rockies on the readiness with which oceanic cyclones pass inland during the cold season.

The foregoing suggestions are tentative and include those items which in the opinion of the writer would yield the most helpful results. Atlantic pressure is important, but must take a subordinate place to that of the Pacific. The hope of the future so far as seasonal forecasting for the United States is concerned lies in the Pacific.

LITERATURE CITED

(1) WALKER, SIR G. T.
1924. CORRELATIONS IN SEASONAL WEATHER.
Memoirs of the Indian Met'l Dept., 24: parts 4, 9, and others.
(2) Met. Zeit., 15: 85–105, 1898.
(3) Mo. Wea. Rev., 36: 435.
(4) WALKER, SIR G. T.
1924. CORRELATIONS IN SEASONAL WEATHER.
Memoirs of the Indian Met'l Dept., 24: part 9, 283.
(5) OKADA, T.
1916. SOME RESEARCHES IN THE FAR EASTERN SEASONAL CORRELATIONS.
Mo. Wea. Rev., 44: 17.
1917. ibid., 45: 238 and 299.
1920. ibid., 48: 102.
(6) Bull. Cent. Met'l Observatory, Japan, 1: no. 1; and Memoirs Imp. Obs., Kobe, 1: no. 1.
(7) MOSSMAN, R. C.
SOUTHERN HEMISPHERE SEASONAL CORRELATIONS.
Symon's Met'l Mag., 48: 2, 44, 82, 104, 119, 160, 200, 226.
(8) BLAIR, T. A.
1917. SOME TEMPERATURE CORRELATIONS IN THE UNITED STATES.
Mo. Wea. Rev., 45: 444.
(9) REED, CHARLES D.
1925. MONTHLY FORECASTS BY CORRELATION.
Mo. Wea. Rev., 53: 249.
(10) Geophys. Memoirs no. 10, Met'l Office, London, 1914, 212.
(11) WALKER, SIR G. T.
1924. CORRELATIONS IN SEASONAL WEATHER.
Memoirs of the Indian Met'l Dept., 24: part 9, 332.

ON THE RELIABILITY OF HAIR HYGROMETERS

By L. T. SAMUELS

[U. S. Weather Bureau, Washington, D. C., December 9, 1925]

Humidity data recorded by the Weather Bureau are obtained chiefly from observations with psychrometers, supplemented at a few stations by records from hair hygrographs, the former, however, always being regarded as the standard. As is well known, the manipulation of the psychrometer at temperatures below freezing requires special care and considerably more time than at higher temperatures. With a view toward effecting an improvement in humidity determinations during low temperatures a hair hygrograph was exposed to various temperatures and humidities and its performance observed in relation to simultaneous readings of a whirling psychrometer exposed to the same conditions. The results obtained, preceded by a brief statement regarding the characteristics of both types of instruments, will now be presented.

The principal reason for the wide use of the psychrometer as compared with other types of hygrometers is the constancy of its indications, a truly valuable asset in any scientific instrument. However, it has frequently been used as a standard of reference under conditions where part of the so-called "error" of the compared instrument was the error of the psychrometer. Under the best conditions, i. e., when both thermometers are accurate, the wet bulb properly covered and moistened, the exposure and ventilation adequate, and the temperature *above* freezing, the humidity measurements from a psychrometer will be accurate within about 2 per cent, but if either the temperature or relative humidity is low, or the air approaching saturation, the errors may be larger than 10 per cent.[1] When the temperature is below freezing the errors of observation due to the smallness of the quantities to be measured are often exceedingly large, making other methods preferable at such times. For example, a depression of only 0.1° C. corresponds to a difference of 5 per cent in the relative humidity at −15° C., 7 per cent at −20° C., 18 per cent at −30° C., and 45 per cent at −39° C. Another source of uncertainty is the thickness of the ice covering the wet bulb, which, if more than a very thin film, appreciably retards the cooling of the bulb.

The most important defect in the hair hygrometer is the variability of its zero, a fact which is, however, often exaggerated in comparison with psychrometers, owing to the bad condition of the former as well as inaccuracies in the latter. In northern Europe and other regions where low temperatures are more or less common the hair hygrometer has been found very satisfactory, and wide experience has unquestionably shown that when properly cared for it is an excellent instrument. The technique of hygrometry is summarized in considerable detail in numerous publications.[2]

Mr. C. S. Ling, official in charge, of the aerological station at Drexel, Nebr., began early in 1924 a series of comparisons between a psychrometer and hair hygrograph. Owing to the fact that electric power for operating the ventilating fans could not always be obtained when desired at Drexel, these observations were trans-

[1] Shaw, A. Norman, Trans. Royal Soc. Canada. Vol. 10, 1916.

[2] "A Discussion on Hygrometry," by Shaw, Simpson, Griffiths, and others. Proc. Phys. Soc. of London, 1921–22, vol. 34; "Errors of Absorption Hygrometers." Annals Astron. Obs., Harvard Coll., Vol. LVIII, Pt. II, 1906, by S. P. Fergusson; and in less detail in the article on "Humidity" by Skinner in "A Dictionary of Applied Physics," vol. 3, Glazebrook and others, London, 1923, and by S. P. Fergusson, "Methods for measuring humidity," Jour. of the Optical Soc. of Amer. and Rev. of Scient. Inst., vol. 10, No. 1, January, 1925.